D1-82-0404

BOEING SCIENTIFIC RESEARCH LABORATORIES

Thermal Anomalies on the Totally Eclipsed Moon of December 19, 1964

J. M. Saari

R. W. Shorthill

January, 1965

Geo Astrophysics Laboratory

D1-82-0404

THERMAL ANOMALIES ON THE TOTALLY ECLIPSED MOON OF DECEMBER 19, 1964

by

J. M. Saari and R. W. Shorthill

Geo-Astrophysics Laboratory

Boeing Scientific Research Laboratories

Seattle, Washington 98124

Submitted to Nature for Publication

January, 1965

ABSTRACT

The lunar disk was scanned in the infrared nine times during the total eclipse of December 19, 1964 using the 74-inch Kottamia telescope in Egypt. As expected from previous work, the major ray craters cooled less rapidly than their environs. However, hundreds of localized hot spots were discovered on the disk, some of which have been identified with small ray craters. Mare Humorum and certain portions of other seas were found to be thermally enhanced compared to their surroundings.

THERMAL ANOMALIES ON THE TOTALLY ECLIPSED MOON OF DECEMBER 19, 1964

Recent infrared measurements on small portions of the lunar disk made during eclipses[1,2] and during the lunar night[3,4] have revealed prominent thermal anomalies on ray craters, and lesser anomalies in other areas. A survey of the entire lunar disk is needed to determine the thermal homogeneity of the surface. While such a survey is possible for the dark side of the Moon, the low temperatures there require a slow scanning rate and observations over many nights. During a total lunar eclipse, however, the surface cools for only a short period, and its substantially higher temperature allows rapid scanning during totality.

In 1962 we developed a rapid scan system for mapping the Moon thermally and photometrically under illumination, using the 60-inch telescope at Mount Wilson[4]. The scan system was modified for use on the 74-inch Kottamia telescope of the Helwan Observatory in Egypt for observations during the total lunar eclipse of December 19, 1964. Using a mercury-doped germanium detector cooled to liquid neon temperature, we were able to scan the entire disk in 16 minutes at 10" arc resolution with approximately 200 successive traverses. Four scans were made on the full Moon before the eclipse began, four during the first penumbral phase, three during totality, and one during the second penumbral phase.

These data were recorded on magnetic tape and are now being reduced on a 7094 computer.

A great amount of detail was revealed by chart recordings made during the experiment and is the basis for this preliminary report. As expected, prominent anomalies were found on the major ray craters Tycho, Copernicus, Aristarchus, Aristoteles, Proclus, Theophilus, Langrenus and Stevinus. For example, Fig. 1 is a tracing of the infrared signal obtained on a traverse through Tycho, an outstanding thermal anomaly on the eclipsed Moon. Preliminary calculations indicate the maximum temperature on Tycho is 226°K and the environ temperature 178°K, a difference of 48°K. On this traverse three peaks in the signal over Tycho may correspond to the rims and the central peak.

Perhaps the most surprising result of the experiment was the discovery of hundreds of localized thermal anomalies or "hot spots" on the surface of the Moon besides those associated with the major ray craters. An example in Fig. 1 is the "spike" in the signal near Tycho, tentatively identified with Heinsius A. Other examples of hot spots are seen in Fig. 2 where seven spikes in the signal correspond to locations in Mare Tranquillitatis and Mare Foecunditatis and on the edges of Mare Imbrium and Mare Serenitatis. The largest spike on the chart recordings, comparable to the signal from Tycho, was observed from the crater Dawes.

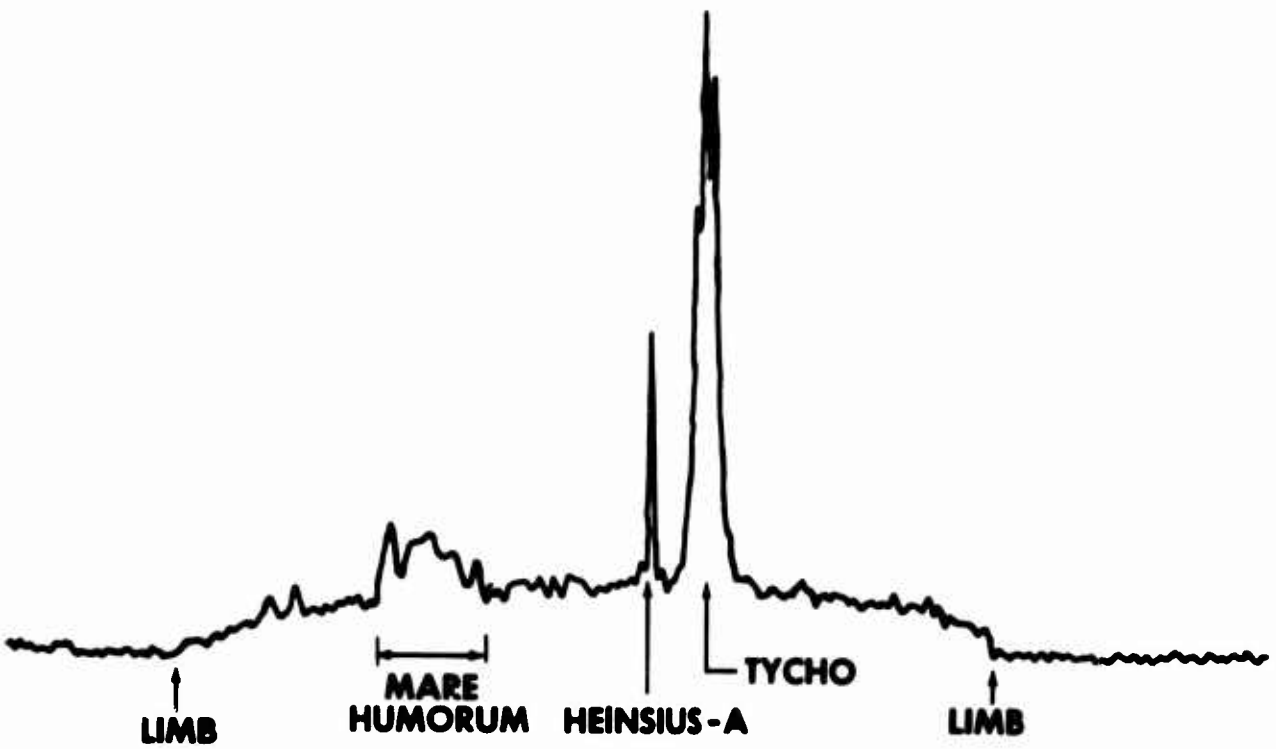

Fig. 1. Tracing of the infrared signal obtained on traverse number 31 during the third scan in totality of the December 19, 1964 total lunar eclipse. The scan began at $2^h55.^m0$ UT and ended at $3^h10.^m4$ UT.

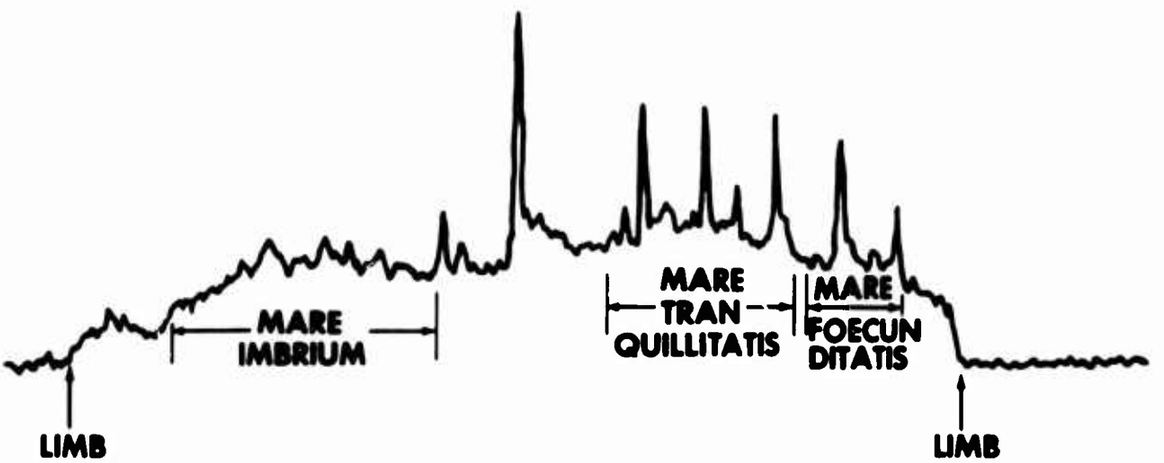

Fig. 2. Tracing of the infrared signal on traverse 134 during the third scan in totality.

The positions of 300 of the more conspicuous hot spots are plotted in Fig. 3, where the boundaries between the seas and continental areas are indicated. The distribution of these anomalies is not uniform on the disk; for instance a great number are found in Mare Tranquillitatis and relatively few in the continental area between Tycho and Theophilus. Many hot spots can be identified with the small ray craters which appear as white spots on the full Moon; these youthful features probably are thermally anomalous, as are the major ray craters, by reason of their denser and/or rougher surfaces. Some hot spots, however, are not associated with small ray craters; accurate positioning will be the first step in seeking an interpretation for these anomalies.

Another important result is the discovery of thermal enhancements over extended regions of the seas as shown in Fig. 1. Some of these extended enhancements are plotted in Fig. 3 as lines along the traverse direction. All of Mare Humorum appears higher in temperature than its environs while only parts of Oceanus Procellarum, Mare Imbrium, and Mare Frigoris are elevated. Extended enhancements are also found in Mare Tranquillitatis and Mare Foecunditatis as shown in Fig. 2.

The significance of these results will become clearer after contour maps are plotted and cooling curves for specific areas of interest are constructed. The observed thermal

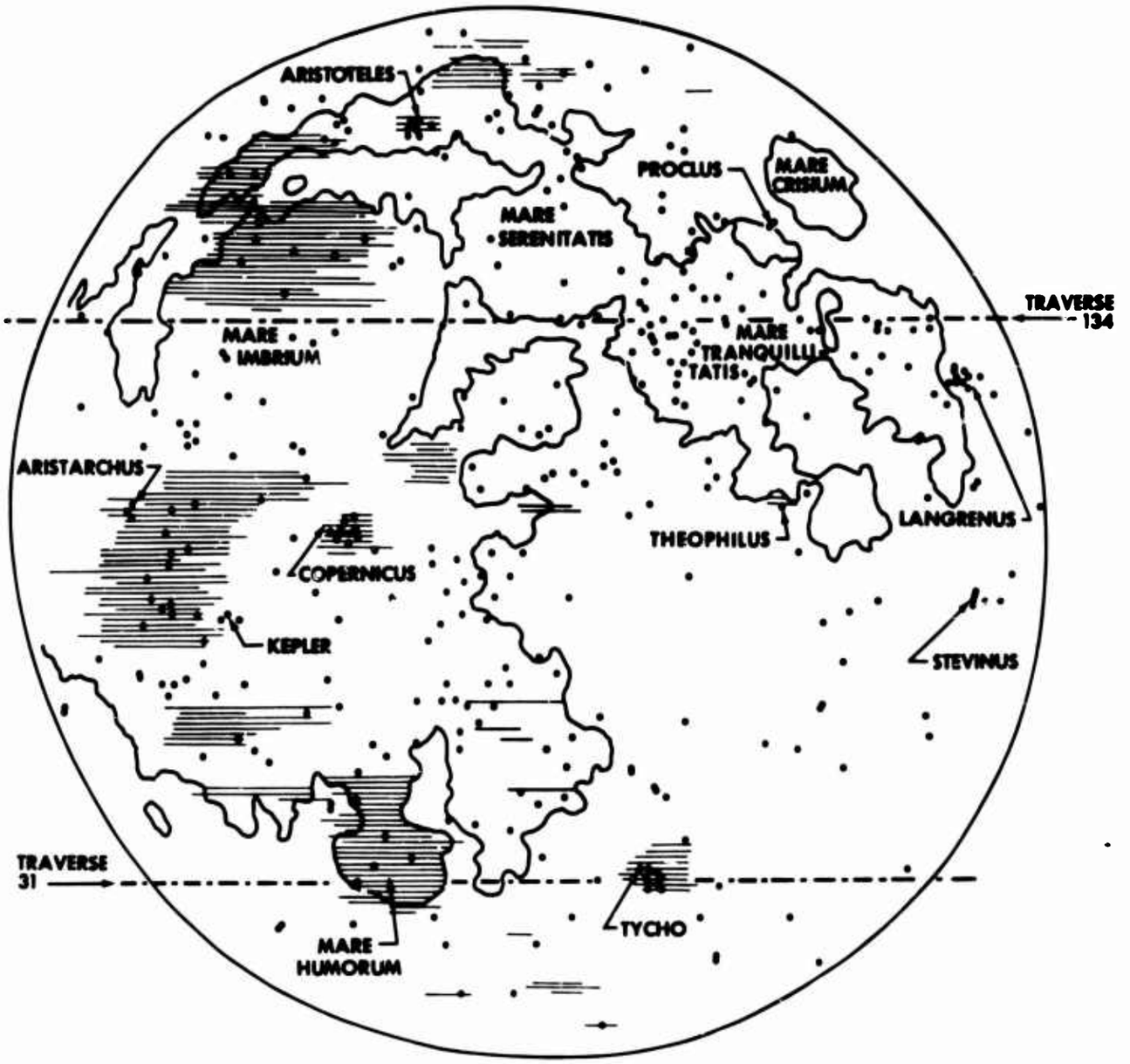

Fig. 3. Positions of "spikes" in the infrared signal (indicated by dots) obtained during the third scan in totality. Some of the extended thermal enhancements are indicated by lines in the traverse direction (see text). Traverses 31 and 134 are indicated by dot-dash lines.

anomalies will be plotted on maps of the lunar disk and compared with surface features. The interpretation of the results can then be made with respect to theoretical cooling curves and experimental data such as albedo, color contrasts, stratigraphy, radar, and infrared measurements through a lunation.

We wish to thank Professor A. H. Samaha, Director of the Helwan Observatory, for generous allowance of observing time on the 74-inch reflector at Kottamia; to Dr. M. K. Aly, Assistant Director, for collaboration at the telescope; and to G. K. Bruce for assistance in carrying out the measurements. Transport of the equipment was made possible through the cooperation of Dr. J. F. Salisbury, Chief of Lunar-Planetary Research, United States Air Force Cambridge Research Laboratories, under contract number AF19(628)-4371.

REFERENCES

1. Saari, J. M. and Shorthill, R. W., Icarus, 2, 15 (1963).

2. Sinton, W. M., Lowell Obs. Bull., 5, 25 (1960).

3. Murray, B. C. and Wildey, R. L., Astrophys. J., 139, No. 2, 734 (1964).

4. Shorthill, R. W. and Saari, J. M., Paper presented at the Conference on Geological Problems in Lunar Research sponsored by the New York Academy of Sciences, New York, May 16-19, 1964 (in press).

DISTRIBUTION LIST FOR THIS DOCUMENT

Dr. Arthur Adel
Atmospheric Research
Observatory
Arizona State College
Flagstaff, Arizona

Dr. H. W. Babcock
Mt. Wilson & Palomar
Observatories
813 Santa Barbara Street
Pasadena, California

Dr. William P. Bidleman
The Observatory
University of Michigan
Ann Arbor, Michigan

Dr. D. E. Bode
Santa Barbara Research Center
Santa Barbara Airport
Goleta, California

Mr. Charles Campen, Jr.
Jet Propulsion Laboratory
Pasadena, California

Dr. J. F. Cronin
Terrestrial Sciences Laboratory
Air Force Cambridge Research
Laboratories (CRT)
Bedford, Massachusetts

Dr. David D. Cudaback
Radio Astronomy Laboratory
University of California
Berkeley 4, California

Mr. Charles D. Cochran
Marshall Space Flight Center
M-RP-T
Bldg 4488
Huntsville, Alabama

Mr. John A. Eddy
High Altitude Observatory
Boulder, Colorado

Dr. John V. Evans
Lincoln Laboratories
Massachusetts Institute of
Technology
Cambridge 73, Massachusetts

Dr. John E. Gibson, Code 7132
Radio Astronomy Branch
Naval Research Laboratory
Washington, D. C.

Dr. Seymour L. Goldblatt,
Director
Upper Atmosphere Physics Lab.
NRA Incorporated
3501 Queens Boulevard
Long Island City 1, New York

Dr. Bruce W. Hapke
Center for Radio Physics and
Space Research
Cornell University
Phillips Hall
Ithaca, New York

Dr. Gerard P. Kuiper
Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona

Dr. Heinz H. Lettau
University of Wisconsin
Madison 6, Wisconsin

Dr. Thomas A. Matthews
California Institute of
Technology
Radio Astronomy Dept.
1201 E. California Boulevard
Pasadena, California

NASA
George C. Marshall Space
Flight Center
Huntsville, Alabama

ATTN: M-SAT, Mr. D. J. Winslow

Dr. Donald E. Osterbrock
Washburn Observatory
University of Wisconsin
Madison 6, Wisconsin

Perkins Observatory
Delaware, Ohio

ATTN: Walter E. Mitchell, Jr.

Dr. John W. Salisbury
Chief of the Lunar Exploration Branch
Air Force Cambridge Research Laboratories
Bedford, Massachusetts

Dr. T. B. A. Senior
Radiation Laboratory
University of Michigan
Ann Arbor, Michigan

Dr. Martin J. Swetnick
NASA
Code: SL
Washington 25, D. C.

Dr. A. E. Whitford, Director
Lick Observatory
Mount Hamilton, California

Dr. R. A. J. Coutrez
Laboratoire de Radioastronomie
Observatoire Royal de Belgique
3 Av.
Circulaire, Uccle
Belgium

Dr. J. F. Denisse
Observatoire de Meudon
(Seine-et-Oise)
France

Director
Gothard Astrophysical Observatory
Szombathely, Hungary

Dr. G. Fielder
University of London Observatory
Mill Hill Park
London, N. W. 7,
England

Professor Zdenek Kopal
Dept. of Astronomy
University of Manchester
Manchester, England

Dr. Donald A. MacRae
Dunlap Observatory
Richmond Hill, Ontario

Dr. E. R. Mustel
B. Gruzinskaya 10
Astronomical Council
Moscow G. 242
U.S.S.R.

Dr. R. M. Petrie
Dominion Astrophysical Observatory
R. R. 7
Victoria, B. C.

Professor Svein Rosseland
The Institute of Theoretical Astrophysics
Blindern, Norway

Dr. S. K. Runcorn
University of Durham
Physics Department
King's College
Newcastle Upon Tyne, I
England

Dr. A. B. Severny, Director
Crimean Astrophysical Observatory
Crimea, P/O Nauchny
U.S.S.R.

Dr. V. S. Troitski
Research Institute of Radiophysics
Gorky, U.S.S.R.

Dr. John Halajian
Grumman Aircraft Engineering Corp.
Plant 5
Bethpage, New York

Mr. John Rinehart
Colorado School of Mines
Golden, Colorado

Mr. Bruce Hall
ENGMC-ED
Office, Chief of Engineers
Bldg. T-7
Gravelly Point
Washington 25, D. C.

Mr. Donald F. Saunders
Texas Instruments Inc.
P. O. Box 35084
Dallas, Texas

Dr. Jack Van Lopik
Science Services Division
Texas Instruments Inc.
P. O. Box 35084
Dallas, Texas

Dr. Konrad Buettner
Department of Meteorology
University of Washington
Seattle 5, Washington

Mr. Lloyd B. Craine
Division of Industrial Research
Washington State University
Pullman, Washington

Mr. G. A. Derbyshire, Secretary
Space Science Board
National Academy of Sciences
2101 Constitution Ave., N. W.
Washington 25, D. C.

Mr. Donald R. Dobrott
22A Escondido Village
Stanford, California

Dr. Robert Fleischer
3712 Garfield Street N. W.
Washington 7, D. C.

Mrs. Jacquelyn Freeberg,
Librarian
Branch of Astrogeology
345 Middlefield Road
Menlo Park, California

Mr. Ted Foster
Department of Physics
University of Washington
Seattle 5, Washington

Dr. George Gassmann
Civilian Air Terminal
Bedford, Massachusetts 01730

Professor R. Geballe
Department of Physics
University of Washington
Seattle 5, Washington

Dr. J. J. Gilvarry
Mail Zone 596-00X
General Dynamics Astronautics
Kearney Villa Road
San Diego, California

Professor T. Gold
Center for Radio Physics and
Space Research
Cornell University
Ithaca, New York

Dr. Leo Goldberg
Harvard College Observatory
Cambridge 38, Massachusetts

Professor F. T. Haddock
Department of Radio Astronomy
University of Michigan
Ann Arbor, Michigan

Dr. Charles Hyder
Department of Astronomy
University of California
Los Angeles, California 90024

Mr. Hector Ingrao
Harvard College Observatory
Cambridge 38, Massachusetts

Dr. Francis S. Johnson
Southwest Center for Advanced
Studies
P. O. Box 8478
Dallas 5, Texas

Mr. Robert L. Jones
Space Environment Division
NASA - Manned Spacecraft Center
P. O. Box 153[illegible]
Houston, 1, Texas

Dr. M. R. Kundu
Cornell University
Department of Astronomy
Ithaca, New York

Dr. Harold Leinbach
Department of Physics and
Astronomy
State University of Iowa
Iowa City, Iowa

Engineering Library
213 Guggenheim
University of Washington
Seattle 5, Washington

Library
Central Radio Propagation Lab.
National Bureau of Standards
Boulder, Colorado

Library
Goddard Space Flight Center
NASA
Greenbelt, Maryland

Library
High Altitude Observatory
University of Colorado
Boulder, Colorado

Florence C. Lister, Librarian

Huston Denslow, Library Supervisor
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California

Library
Planning Research Corporation
1333 Westwood Boulevard
Los Angeles 24, California

Attn: Mrs. Donna Neumann

Library
Rand Corporation
1700 Main Street
Santa Monica, California

Dr. Harold B. Liemohn
Southwest Center for Advanced Studies
P. O. Box 8478
Dallas 5, Texas

Mr. Donald S. Lund
High Altitude Observatory
Boulder, Colorado

Mr. Charles P. Martens
Melpar, Incorporated
Exploratory Research Laboratory
3000 Arlington Boulevard
Falls Church, Virginia

Dr. Alan S. Meltzer
Rensselaer Polytechnic Institute
Troy, New York

Dr. Donald H. Menzel, Director
Harvard College Observatory
Cambridge 38, Massachusetts

Dr. S. N. Milford
Research Department
Grumman Aircraft Engineering Corporation
Bethpage, New York

NASA
Manned Space Craft Center
Houston 1, Texas

Attn: Mr. Warren Gillespie, Jr.

Dr. Ludwig F. Oster
Box 2023, Yale Station
Yale University Observatory
New Haven, Connecticut

Professor Wolfgang Priester
NASA
Goddard Space Flight Center
Institute for Space Studies
475 Riverside Drive
New York 27, New York

Dr. Marion C. Rinehart
Philco Western Development Labs.
Space Sciences Department
3875 Fabian Way
Palo Alto, California

Dr. Eugene M. Shoemaker
U. S. Geological Survey
345 Middlefield Road
Menlo Park, California

Professor A. G. Smith
Department of Physics
University of Florida
Gainesville, Florida

Space Technology Laboratories
STL Technical Library
One Space Park
Redondo Beach, California

Dr. Robert J. Stewart
Project Engineer
Gruman Aircraft Engineering Corp.
Long Island, New York

Professor H. M. Swarm
Department of Electrical Eng.
University of Washington
Seattle 5, Washington

Dr. J. Irvin Swigart
Upper Air Research Laboratory
University of Utah
Salt Lake City 12, Utah

Professor J. A. Van Allen
Physics and Astronomy Department
University of Iowa
Iowa City, Iowa

William W. Vaughan
Code: M-Aero-G
Aeroballistics Division
Marshall Space Flight Center
Huntsville, Alabama

Dr. A. J. Zmuda
Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland

Professor Massimo Cimino
Osservatorio Astronomico
Su Monte Mario
Via Triojale, 204 - Roma
Italy

Dr. G. Day
Australian National Radio
Astronomy Observatory
P. O. Box 189
Parkes, Australia

Directorate of Scientific
Information Services
Defence Research Board
Dept. of National Defence Hdqs.
Cartier Square, "A" Bldg.
Ottawa 4, Ontario

Dr. Oystein Elgaroy
Institute of Theoretical Astro-
physics
University of Oslo
Oslo, Norway

Dr. Gunner Eriksen
Institute of Theoretical Astro-
physics
Oslo-Blindern
Norway

Professor Yoshio Fujita
Department of Astronomy
Faculty of Science
University of Tokyo
Tokyo, Japan

Geophysical Institute
University of Alaska
College, Alaska

Herr Professor Otto Hachenberg
Radiosternwarte
Poppelsdorfer Allee 49
Bonn, West Germany

Dr. J. S. Hey
Royal Radar Establishment
Radio Astronomy Division
Malvern, Worcestershire, England

Dr. J. A. Jacobs, Director
University of British Columbia
Institute of Earth Sciences
Vancouver 8, Canada

Dr. A. Kimpara
Research Institute for Atmos-
pherics
Nagoya University
Toyokawa
Aichi, Japan

Professor V. A. Krat
Pulkovo Observatory
Leningrad, U.S.S.R.

Physics Department Library
University of Queensland
Brisbane, Australia

Dr. F. Link
Astronomical Institute
Prague 2
Budecske 6, Czechoslovakia

Sir Bernard Lovell
University of Manchester
Nuffield Radio Astronomy Labs.
Jodrell Bank
Macclesfield
Cheshire, England

Dr. Fernando de Mendonca
Comissao Nacional de Atividades Espaciais
Sao Jose dos Campos (SP)
Brasil

Professor M. G. J. Minnaert
Sterrenwacht Sonnenborgh
UTRECHT
The Netherlands

Dr. Mollwo
Deutsche Akademie der Wissenschaften
Heinrich-Hertz-Institut
Berlin-Adlershof, Asphaltstrasse
a.d. Rudower Chaussee
Germany

Professor T. Obayashi
Ionosphere Research Laboratory
Kyoto University
Kyoto, Japan

Kiruna Geophysical Observatory
Kiruna C
Sweden

Dr. Herbert S. Polin
Laboratoire de Recherches Physiques
Veyrier
(Geneva), Switzerland

Professore G. Righini
L'Osservatorio Astrofisico di Arcetri
Firenze, Italia

Dr. Juan G. Roederer, Jefe
Laboratorio de Radiacion Cosmica
Facultad de Ciencias Exactas
Peru 272
Buenos Aires, Argentina

Dr. A. Romana
Observatorio del Ebro
Apartade 9, Tortosa (Tarragona)
Spain

Dr. O. E. H. Rydbeck
Research Laboratory of Electronics
Chalmers University of Technology
Gothenburg, Sweden

Professor M. Ryle
Mullard Radio Astronomy Observatory
Cavendish Laboratory
Cambridge, England

Dr. N. A. Savich
Crimean Astrophysical Observatory
U.S.S.R. Crimea

Dr. K. Sinno
Hiraiso Radio Wave Observatory
Nakaminato
Ibarg, Japan

Dr. Richard O. Stenerson
Department of Physics
University of Utah
Salt Lake City 12, Utah

Dr. Govinda Swarup
Radio Astronomy Group
Tata Institute of Fundamental Research
Colaba
Bombay 5, India

Dr. T. Takakura
Tokyo Astronomical Observatory
University of Tokyo
Tokyo, Japan

Dr. H. Tanaka
Research Institute for Atmospherics
Nagoya University
Toyokawa, Aichi, Japan

Dr. J. P. Wild
Radiophysics Laboratory
C.S.I.R.O.
Sydney, Australia

Dr. Gerald F. Anderson
High Altitude Observatory
Boulder, Colorado

Dr. J. Katzman
National Research Council
Sussex Drive
Ottawa 2, Canada

Professor R. W. E. McNicol
Department of Physics
University of Queensland
Brisbane, Australia

Dr. Arthur Aikin
Code 615
Goddard Flight Center
Greenbelt, Maryland

Mr. B. E. Berson
General Dynamics
Pomona, California
6-91

Dr. Harry Elliott
Imperial College
London, England

Mr. Paul G. Herold
Colorado School of Mines
Golden, Colorado

Dr. Donald Hale
R-RP-N
George C. Marshall Space Flight
Center
Huntsville, Alabama

The Librarian
C.S.I.R.O.
Radiophysics Laboratory
University Grounds
City Road
Chippendale, N.S.W.,
Australia

Dr. Andres D. Sanchez
Arecibo Ionospheric Observatory
Box 995
Arecibo, Puerto Rico

Dr. O. Lyle Tiffany
Chief Scientist
Bendix Systems Division
The Bendix Corporation
Ann Arbor, Michigan